

# On the electron temperature determination in high-metallicity H II regions

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## ABSTRACT

The problem of determination of the electron temperature  $t_2$  in the  $O^+$  zone of high-metallicity H II region was examined. It was shown that the ratio of nebular to auroral nitrogen line intensities, which is an indicator of the electron temperature  $t_2$ , can be expressed in terms of the nebular line intensities of oxygen. This solves the problem of the determination of the electron temperature  $t_2$ , since the oxygen nebular lines are strong and, consequently, are readily observable. A relation between electron temperatures in the  $O^+$  and  $O^{++}$  zones in high-metallicity H II regions was studied. It was found that there is no one-to-one correspondance between  $t_2$  and  $t_3$  temperatures. Instead the  $t_2 - t_3$  relation is dependent on excitation parameter.

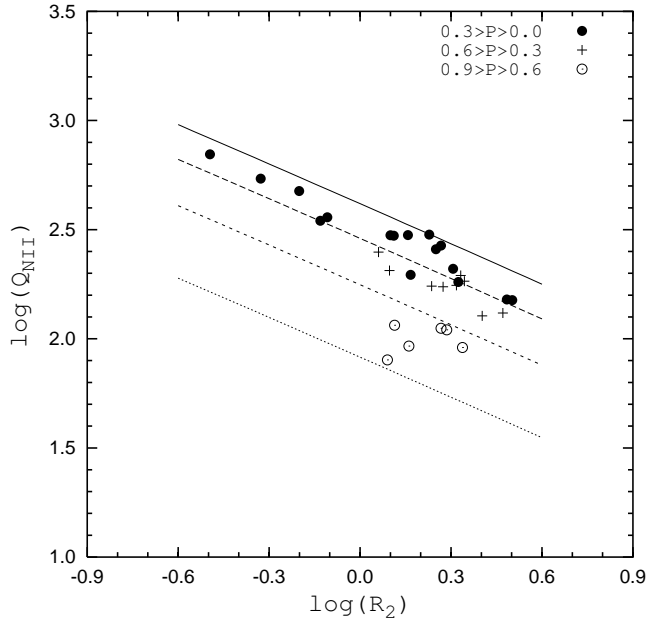
**Key words:** galaxies: abundances – ISM: abundances – H II regions

## 1 INTRODUCTION

The oxygen abundance is one of the fundamental characteristics of a galaxy. Accurate oxygen abundances are mandatory in investigations of different aspects of the formation and evolution of galaxies. Accurate oxygen abundances in H II regions can be derived via the classic  $T_e$  method. In the first step, the electron temperature  $t_3$  within the [O III] zone and the electron temperature  $t_2$  within the [O II] zone are determined. Then the abundance is derived using the equations linking the ionic abundances to the measured line intensities and electron temperature. (The usual notation  $(O/H)_{T_e}$  for the oxygen abundance derived with the  $T_e$  method will be used throughout the paper.) The ratio of nebular to auroral oxygen line intensities  $Q_{OIII} = [O III]\lambda 4959 + \lambda 5007 / [O III]\lambda 4363$  is used for the  $t_3$  determination. The ratio of nebular to auroral oxygen line intensities  $Q_{OII} = [O II]\lambda 3727 / [O II]\lambda 7320 + \lambda 7330$  or the ratio of nebular to auroral nitrogen line intensities  $Q_{NII} = [N II]\lambda 6548 + \lambda 6584 / [N II]\lambda 5755$  are used for the  $t_2$  determination. Unfortunately, the auroral lines are faint and drop below detectability in the spectra of high-metallicity H II regions. This prevents the application of the  $T_e$  method to high-metallicity H II regions.

Is there another way to estimate electron temperature in H II region where the faint auroral lines are not detected? The law of energy conservation for free electrons (e.g. Sobolev 1967) shows that the electron temperature in a nebula is mainly defined by the hardness of the ionizing radiation and by the emission in the forbidden lines. Since

the excitation parameter  $P$  is an indicator of the hardness of the ionizing radiation, one can expect that the excitation parameter  $P$  coupled with the measured intensities of the nebular oxygen lines can be used to estimate the electron temperature in H II regions. We have suggested that the parametric calibration links the oxygen abundance to the measured nebular oxygen line intensities and the excitation parameter  $P$  ( $P$  calibration or  $P$  method) (Pilyugin 2000, 2001a, 2003). (The oxygen abundance derived with the  $P$  calibration will be referred to as  $(O/H)_P$ .) Comparisons between  $(O/H)_{T_e}$  and  $(O/H)_P$  abundances in H II regions with direct measurement of the electron temperature as well as the comparison between radial distributions of  $(O/H)_{T_e}$  and  $(O/H)_P$  abundances in the disks of a few well studied spiral galaxies show that  $(O/H)_P$  abundances are in agreement with  $(O/H)_{T_e}$  abundances (Pilyugin 2001b; Pilyugin et al. 2003, 2004; Pilyugin & Thuan 2005). This indirectly confirms that the physical conditions in the H II region can be estimated via the nebular oxygen line intensities and the excitation parameter  $P$ . (Or one may also say that the physical conditions in the H II region can be estimated via the nebular oxygen line intensities only, since the excitation parameter  $P$  is expressed in terms of these lines.) If this is the case, then one can expect that the diagnostic line ratios can be expressed in terms of the intensities of the oxygen nebular lines. Indeed, it has been found empirically that there is a relationship (the ff relation) between auroral [O III] $\lambda 4363$  and nebular oxygen line intensities in spectra of H II regions (Pilyugin 2005; Pilyugin et al. 2006a). In other words, the diagnostic line ratio  $Q_{OIII}$ , used for the



**Figure 1.** Plot of  $\log(Q_{\text{NII}})$  as a function of  $\log(R_2)$  for a sample of H II regions. The filled circles are H II regions with  $0 < P < 0.3$ . The plus signs are those with  $0.3 < P < 0.6$ . The open circles are those with  $P > 0.6$ . The relations corresponding to Eq.(2) for different values of the excitation parameter are shown by the solid ( $P = 0.0$ ), long-dashed ( $P = 0.3$ ), short-dashed ( $P = 0.6$ ), and dotted ( $P = 0.9$ ) lines.

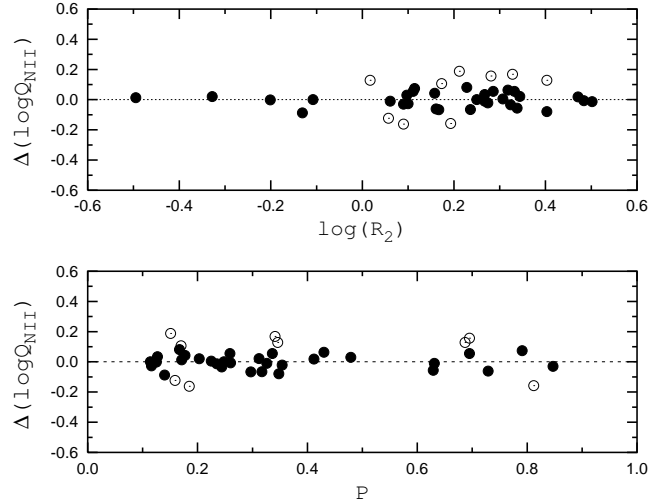
determination of the electron temperature within the [O III] zone, can be expressed in terms of the nebular oxygen line intensities. It has also been suggested that the electron temperature  $t_2$  within the [O II] zone is related to the electron temperature  $t_3$  within the [O III] zone (Campbell et al. 1986; Pagel et al. 1992; Izotov et al. 1997; Deharveng et al. 2000; Oey & Shields 2000; Pilyugin et al. 2006b). Then one can expect that the diagnostic line ratio used for the determination of the electron temperature within the [O II] zone, can also be expressed in terms of the nebular oxygen line intensities. The goal of this paper is to establish this relation.

The paper is organized as follows. A relation between the ratio of nebular to auroral nitrogen line intensities and oxygen nebular line intensities,  $Q_{\text{NII}} = f(R_2, P)$ , is derived in Section 2. A relation between electron temperatures  $t_2$  and  $t_3$  is discussed in Section 3. We summarize our conclusions in Section 4.

We will be using the following notations throughout the paper:  $R_2 = I_{[\text{O II}]\lambda 3727 + \lambda 3729} / I_{\text{H}\beta}$ ,  $R_3 = I_{[\text{O III}]\lambda 4959 + \lambda 5007} / I_{\text{H}\beta}$ ,  $R = I_{[\text{O III}]\lambda 4363} / I_{\text{H}\beta}$ . With these definitions, the excitation parameter  $P$  can be expressed as:  $P = R_3 / (R_3 + R_2)$ .

## 2 THE RELATION $Q_{\text{NII}} = f(R_2, P)$

The electron temperature  $t_2$  within the  $\text{O}^+$  zone in H II regions can be derived from the diagnostic line ratio  $Q_{\text{OII}}$  or from the diagnostic line ratio  $Q_{\text{NII}}$ . It is believed that the measured  $Q_{\text{NII}}$  results in more reliable  $t_2$  value. Starting from our basic idea that the diagnostic line ratio can be expressed in terms of the strong oxygen nebular line



**Figure 2.** Plot of  $\Delta(\log Q_{\text{NII}})$  as a function of nebular oxygen line intensity  $\log(R_2)$  (top panel) and of excitation parameter  $P$  (bottom panel). The filled circles are H II regions used in deriving the final relation. The open circles are the other H II regions.

intensities, we will search for a relationship of the type  $Q_{\text{NII}} = f(R_2, P)$  here. It should be noted that the ratio of nebular to auroral nitrogen line intensities  $Q_{\text{NII}} = [\text{N II}]\lambda 6548 + [\text{N II}]\lambda 5755$  is an indicator of the electron temperature  $t_2$  and therefore this ratio depends on the electron temperature but not on the nitrogen abundance.

Recent measurements of the oxygen and nitrogen line intensities in high-metallicity ( $12 + \log \text{O}/\text{H} > 8.25$ ) H II regions were taken from Castellanos et al. (2002); Luridiana et al. (2002); Peimbert (2003); Kennicutt et al. (2003); Tsamis et al. (2003); Bresolin et al. (2004) and Bresolin et al. (2005). These spectroscopic data (40 data points) form the basis of the present study.

The value of  $Q_{\text{NII}}$  is shown as a function of the intensity of the nebular oxygen line  $R_2$  in Fig. 1 (the points used in the determination of the final relation are shown). The filled circles are H II regions with  $0 < P < 0.3$ . The plus signs are those with  $0.3 < P < 0.6$ . The open circles are those with  $P > 0.6$ . Inspection of Fig. 1 shows that the value  $Q_{\text{NII}}$  is linked to the intensity of the nebular oxygen line  $R_2$  through a relation of the type

$$\begin{aligned} \log(Q_{\text{NII}}) = & a_0 + a_1 \log(R_2) + a_2 [\log(R_2)]^2 \\ & + b_1 \log(1 - P) + b_2 [\log(1 - P)]^2. \end{aligned} \quad (1)$$

Using a sample of H II regions with measurements of oxygen and nitrogen line intensities, the values of the coefficients in Eq.(1) can be derived. The values of the coefficients in Eq.(1) are derived by using an iteration procedure. In the first step, the relation is determined from all data using the least-square method. Then, the point with the largest deviation is rejected, and a new relation is derived. The iteration procedure is pursued until two successive relations have all their coefficients differing by less 0.001 and the absolute value of the largest deviation is less than 0.1 dex. The following relation was obtained

$$\begin{aligned} \log(Q_{\text{NII}}) = & 2.619 - 0.609 \log(R_2) - 0.010 [\log(R_2)]^2 \\ & + 1.085 \log(1 - P) + 0.382 [\log(1 - P)]^2. \end{aligned} \quad (2)$$

The final relation was obtained using 31 data points out of an original set of 40 points. The relations corresponding to Eq.(2) for different values of the excitation parameter are shown in Fig. 1 by the solid ( $P = 0.0$ ), long-dashed ( $P = 0.3$ ), short-dashed ( $P = 0.6$ ), and dotted ( $P = 0.9$ ) lines.

The differences  $\Delta(\log Q_{\text{NII}})$  between measured values of  $\log Q_{\text{NII}}^{\text{obs}}$  and those  $\log Q_{\text{NII}}^{\text{cal}}$  computed with obtained relation are shown as a function of oxygen line intensity in Fig.2 (top panel) and as a function of excitation parameter  $P$  (bottom panel). The points used in the determination of the final relation are shown by filled circles. The line is the linear best fit to those data derived through the least squares method. For comparison, we also show by open circles the objects that have been rejected by the iteration procedure. Fig. 2 shows that the deviations do not show a correlation either with oxygen line intensity or with excitation parameter.

Examination of Fig.1 and Fig.2 shows that Eq.(2) gives a satisfactory fit to the observational data. It should be noted however that the particular form of the analytical expression adopted here may be questioned. We have chosen a simple form, Eq.(1), but perhaps a more complex expression may give a better fit to the data. Furthermore, the error in measurements of the line  $[\text{NII}]\lambda 5755$  is in excess of 20% (as indicated in original papers) in a number of calibrating H II regions. Perhaps more accurate measurements may result in a more precise relation. Clearly, high-precision measurements of oxygen and nitrogen lines in spectra of H II regions are needed to check the derived relation<sup>1</sup>.

Thus, Eq.(2) confirms our basic idea that the diagnostic line ratio, which is an indicator of the electron temperature  $t_2$ , can be expressed in terms of the oxygen nebular line intensities. Since the oxygen nebular lines are strong and, consequently, are easily observable, Eq.(2) solves the problem of the electron temperature determination in  $\text{O}^+$  zone of H II region where the faint auroral nitrogen line is not detected. It should be emphasized that the obtained relation  $Q_{\text{NII}} = f(R_2, P)$  is a purely empirical relation in the sense that this is the relation between directly measured values and, consequently, this relation is not based on any assumption.

### 3 THE $t_2 - t_3$ RELATION

#### 3.1 One-dimensional $t_2 - t_3$ relation

Here we will consider the  $t_2 - t_3$  relation for our sample of H II regions. The measured  $Q_{\text{NII}}$  values are used to determine the electron temperatures  $t_2$ . To establish an expression that links the electron temperature  $t_2$  to the value of the  $Q_{\text{NII}}$ ,

<sup>1</sup> After this study was carried out, new high-precision measurements of oxygen and nitrogen lines in the spectrum of H II region H1013 of the spiral galaxy M101 were published by Bresolin (2006). This provides an additional possibility to check the derived relations. The measured intensity of  $[\text{NII}]\lambda 5755$  is  $0.0059 \pm 0.0003$  on a scale where  $I_{H\beta} = 1$ , and Eq.(2) results in 0.00600. The measured intensity of  $[\text{OIII}]\lambda 4363$  is  $0.0024 \pm 0.0003$ , and Eq.(5) results in 0.00267. Thus, the differences between measured line intensities and those predicted by our relation is not in excess of the reported uncertainty of the measurement both for  $[\text{NII}]\lambda 5755$  and  $[\text{OIII}]\lambda 4363$  lines.

we have performed a five-level-atom calculation using recent atomic data. The Einstein coefficients for spontaneous transitions and the energy levels for five low-lying levels were taken from Galavís et al. (1997). The effective cross sections or effective collision strengths for electron impact were taken from Hudson & Bell (2005). The effective cross sections are continuous functions of temperatures and are tabulated by Hudson & Bell (2005) at fixed temperatures. The actual effective cross sections for a given electron temperature used here were derived from two-order polynomial fits of the data from Hudson & Bell (2005) as a function of temperature. The expression for the  $H_\beta$  emissivity was taken from Aller (1984). The five-level-atom solution for ion  $\text{N}^+$  results in the following simple expression for the determination of  $t_2$

$$t_2 = \frac{1.111}{\log(Q_{\text{NII}}) - 0.892 - 0.144 \log(t_2) + 0.023 t_2}. \quad (3)$$

The majority of extragalactic H II regions are in the low-density regime (Zaritsky et al. 1994; Bresolin et al. 2005). Therefore the electron density  $n_e = 100 \text{ cm}^{-3}$  was adopted for the five-level-atom calculation, and for this reason there is no  $n_e$ -term in Eq.(3).

The electron temperature  $t_3$  is derived from the  $Q_{\text{OIII}} = R_3/R$  ratio. The relation between  $t_3$  and  $Q_{\text{OIII}}$  is based on the five-level-atom solution. The Einstein coefficients for spontaneous transitions and the energy levels were taken from Galavís et al. (1997), while the effective cross sections for electron impact were taken from Aggarwal & Keenan (1999). Again, the actual effective cross sections for a given electron temperature were derived from two-order polynomial fits of the data from Aggarwal & Keenan (1999) as a function of temperature. The five-level-atom solution for ion  $\text{O}^{++}$  results in following simple expression for the determination of  $t_3$

$$t_3 = \frac{1.432}{\log(Q_{\text{OIII}}) - 0.875 - 0.025 \log(t_3) - 0.020 t_3}. \quad (4)$$

It should be noted that the electron temperatures  $t_3$  derived from Eq.(4) are close to those derived from analogous expressions given in Pagel et al. (1992) and in Izotov et al. (2006).

Fig. 3 shows the  $t_2$  versus  $t_3$  diagram for our sample of H II regions. Since the auroral line  $[\text{OIII}]\lambda 4363$  is not detected in H II regions from our sample, the ff relation

$$\begin{aligned} \log R &= -4.151 - 3.118 \log P + 2.958 \log R_3 \\ &- 0.680 (\log P)^2, \end{aligned} \quad (5)$$

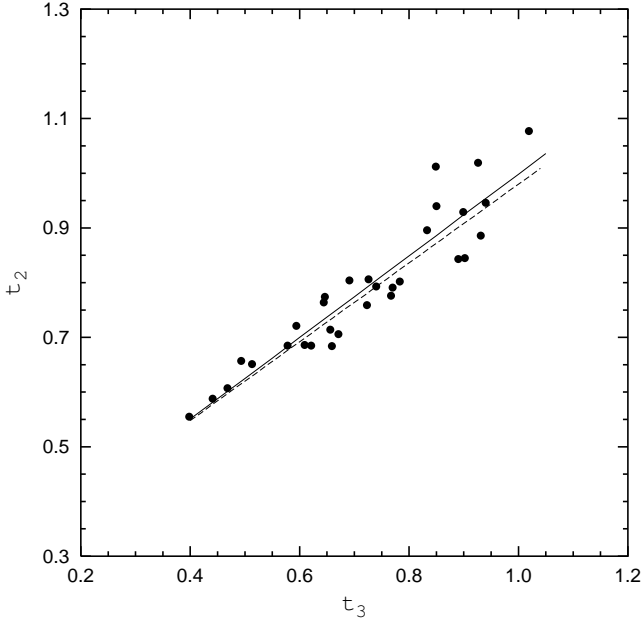
derived in Pilyugin et al. (2006a) was used to estimate the value of  $R$ . The filled circles are individual H II regions. The solid line is the linear best fit to those data

$$t_2 = 0.746 (\pm 0.053) \times t_3 + 0.252 (\pm 0.039) \quad (6)$$

derived through the least squares method. The mean value of residuals to this  $t_2 - t_3$  relation is 0.046.

Recently we have derived a new  $t_2 - t_3$  relation based on the idea that the equation of the  $T_e$  method for  $\text{O}^{++}/\text{H}^+$  applied to the  $\text{O}^{++}$  zone and the equation for  $\text{O}^+/\text{H}^+$  applied to the  $\text{O}^+$  zone must result in the same value of the oxygen abundance (Pilyugin et al. 2006b). The following  $t_2 - t_3$  relation has been derived:

$$t_2 = 0.72 t_3 + 0.26. \quad (7)$$



**Figure 3.** The  $t_2 - t_3$  diagram for our sample of 31 H II regions. The filled circles are individual H II regions. The solid line is the linear best fit to those data derived through the least squares method. The dashed line is the  $t_2 - t_3$  relation derived in our previous study (Pilyugin et al. 2006b).

This relation is shown in Fig. 3 by the dashed line. Inspection of Fig. 3 as well the comparison between Eq.(6) and Eq.(7) shows that the two  $t_2 - t_3$  relations derived in different ways are close to each other.

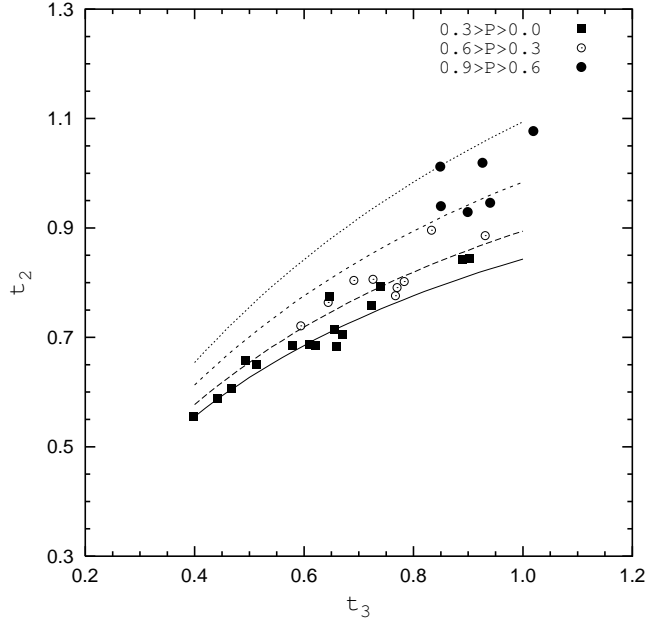
### 3.2 Two-dimensional (parametric) $t_2 - t_3$ relation

Generally speaking, one might expect that there is no one-to-one correspondance between  $t_2$  and  $t_3$  temperatures, and that instead the  $t_2 - t_3$  relation is a function of the excitation parameter  $P$ . We now examine this possibility. Fig. 4 shows the  $t_2$  versus  $t_3$  diagram for our sample of H II regions. The filled squares are H II regions with  $0 < P < 0.3$ . The open circles are those with  $0.3 < P < 0.6$ . The filled circles are those with  $0.6 < P < 0.9$ . Close examination of Fig. 4 suggests that the  $t_2 - t_3$  relationship is not unique but instead is dependent on an additional parameter – the excitation parameter  $P$ . A fit to the data (31 data points) results in

$$\frac{1}{t_2} = 0.410 (\pm 0.028) \times \frac{1}{t_3} - 0.344 (\pm 0.050) \times P + 0.818 (\pm 0.054). \quad (8)$$

The relations corresponding to Eq.(8) for various values of the excitation parameter are shown in Fig. 4 by the solid ( $P = 0.1$ ), long-dashed ( $P = 0.3$ ), short-dashed ( $P = 0.6$ ), and dotted ( $P = 0.9$ ) lines. The mean value of residuals of this  $t_2 - t_3$  relation is 0.030, which is lower by a factor of  $\sim 1.5$  than the analogous value associated with the one-dimensional  $t_2 - t_3$  relation.

Thus, we have found evidence of that there is no one-to-one correspondence between  $t_2$  and  $t_3$  temperatures; instead the  $t_2 - t_3$  relation is dependent on the excitation parameter. The validity of the two-dimensional  $t_2 - t_3$  relation

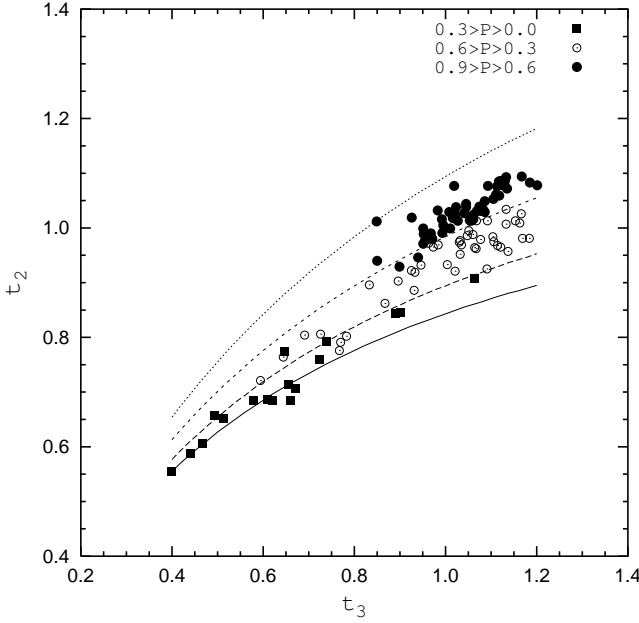


**Figure 4.** The  $t_2 - t_3$  diagram for our sample of H II regions. The filled squares are H II regions with  $0 < P < 0.3$ . The open circles are those with  $0.3 < P < 0.6$ . The filled circles are those with  $0.6 < P < 0.9$ . The relations corresponding to Eq.(8) for different values of the excitation parameter are shown by the solid ( $P = 0.1$ ), long-dashed ( $P = 0.3$ ), short-dashed ( $P = 0.6$ ), and dotted ( $P = 0.9$ ) lines.

can be confirmed (or questioned) by the consideration of an additional sample of H II regions.

Izotov et al. (2004, 2006) have extracted from the Data Release 3 of the Sloan Digital Sky Survey (SDSS) around 4500 spectra of H II regions with an [O III]  $\lambda 4363$  emission line detected at a level better than  $1\sigma$ , and have carefully measured the line intensities in each spectrum. Yuri Izotov and Natalia Guseva have kindly provided me with the total list of their measurements, as only part of these have been published (Izotov et al. 2004, 2006). It constitutes one of the largest and most homogeneous data sets now available, being obtained and reduced in the same way. The ff relation provides a way to select out the H II regions with high quality measurements (Pilyugin & Thuan 2005; Pilyugin et al. 2006a); the discrepancy index  $D_{ff}$  allows us to eliminate low-quality measurements with large  $D_{ff}$ , while retaining high-quality ones with small  $D_{ff}$ . We have extracted a subsample of high-quality (with absolute value of  $D_{ff}$  less than 0.01) measurements of high-metallicity ( $12 + \log(O/H) > 8.25$ ) H II regions. The subsample of 80 H II regions meets that (very hard) precision criterion. The electron temperature  $t_3$  in those H II regions is derived from the measured  $Q_{OIII}$  ratio, The electron temperature  $t_2$  is derived from the  $Q_{NII}$  ratio given by Eq.(2). Those data coupled with the data considered above form the total (extended) sample of 111 data points.

Fig. 5 shows the  $t_2 - t_3$  diagram for the total sample of H II regions. The filled squares are H II regions with  $0 < P < 0.3$ . The open circles are those with  $0.3 < P < 0.6$ . The filled circles are those with  $0.6 < P < 0.9$ . Inspection of Fig. 5 confirms that the  $t_2 - t_3$  relationship is dependent on the excitation parameter  $P$ . A fit to those data (111 data



**Figure 5.** The  $t_2 - t_3$  diagram for extended sample of H II regions. The filled squares are H II regions with  $0 < P < 0.3$ . The open circles are those with  $0.3 < P < 0.6$ . The filled circles are those with  $0.6 < P < 0.9$ . The relations corresponding to Eq.(9) for different values of the excitation parameter are shown by the solid ( $P = 0.1$ ), long-dashed ( $P = 0.3$ ), short-dashed ( $P = 0.6$ ), and dotted ( $P = 0.9$ ) lines.

points) gives

$$\frac{1}{t_2} = 0.418 (\pm 0.010) \times \frac{1}{t_3} - 0.348 (\pm 0.017) \times P + 0.806 (\pm 0.018). \quad (9)$$

The relations corresponding to Eq.(9) for different values of the excitation parameter are shown in Fig. 5 by the solid ( $P = 0.1$ ), long-dashed ( $P = 0.3$ ), short-dashed ( $P = 0.6$ ), and dotted ( $P = 0.9$ ) lines. Examination of Eq.(8) and Eq.(9) shows that the  $t_2 - t_3$  relations derived from the two different samples of H II regions are very similar and agree within the formal uncertainties. Thus the derived  $t_2 - t_3$  relation is rather robust. In the following, we will adopt as the  $t_2 - t_3$  relation

$$\frac{1}{t_2} = 0.41 \times \frac{1}{t_3} - 0.34 \times P + 0.81. \quad (10)$$

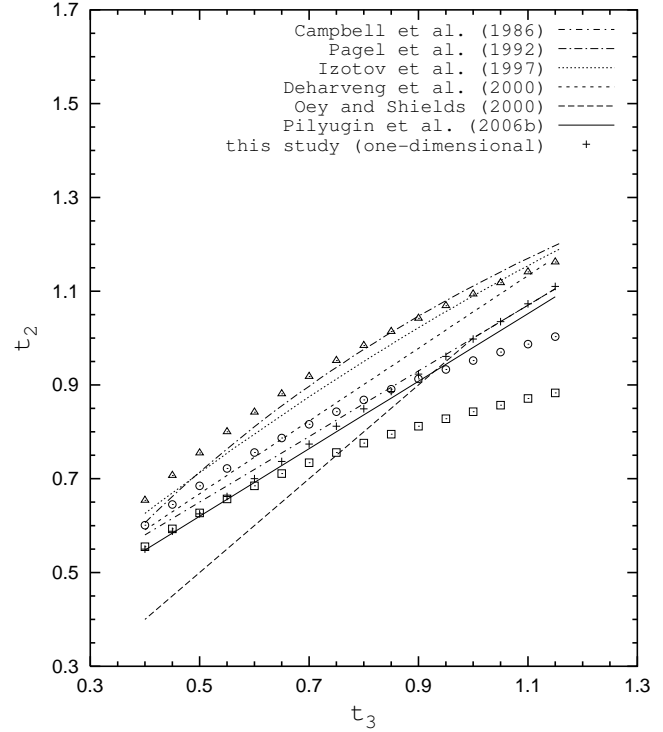
Thus, the consideration of an additional sample of H II regions strengthens the conclusion that the  $t_2 - t_3$  relation is two-dimensional or parametric.

### 3.3 Comparison with previous studies

Several versions of the  $t_2 - t_3$  relation have been proposed. A widely used relation is the one by Campbell et al. (1986) (see also Garnett (1992)) based on the H II region models of Stasińska (1982). Campbell et al. (1986) has found that the  $t_2 - t_3$  relationship can be parametrized as

$$t_2 = 0.7 t_3 + 0.3. \quad (11)$$

Another relation has been proposed by Pagel et al. (1992), also based on H II region model calculations by Stasińska (1990), is:



**Figure 6.** Comparison of the  $t_2 - t_3$  relation derived here with those derived by other investigators. The lines are  $t_2 - t_3$  relations derived in previous works. The one-dimensional  $t_2 - t_3$  relation derived here is shown by the plus signs. The two-dimensional (parametric)  $t_2 - t_3$  relation for different values of the excitation parameter are shown by the triangles ( $P = 0.9$ ), the open circles ( $P = 0.5$ ), and the open squares ( $P = 0.1$ ).

$$\frac{1}{t_2} = 0.5 \left( \frac{1}{t_3} + 0.8 \right). \quad (12)$$

Izotov et al. (1997), who also fitted the H II region models of Stasińska (1990), have proposed the following expression:

$$t_2 = 0.243 + 1.031 t_3 - 0.184 t_3^2. \quad (13)$$

Based on H II region model calculations by Stasińska & Schaerer (1997), Deharveng et al. (2000) have suggested the following relation:

$$t_2 = 0.775 t_3 + 0.281. \quad (14)$$

Oey & Shields (2000) have found that the Campbell et al. relation is reasonable for  $t_3 > 1.0$ . However at lower temperatures, the models are more consistent with an isothermal nebula. They consequently adopted the formulation:

$$t_2 = 0.7 t_3 + 0.3, \quad t_3 > 1.0 \\ t_3, \quad t_3 < 1.0. \quad (15)$$

We now compare the  $t_2 - t_3$  relation obtained here with those obtained by other authors. Since our  $t_2 - t_3$  relation is derived for cool high-metallicity H II regions, the high-temperature low-metallicity part of relation is not considered here. The lines in Fig. 6 are  $t_2 - t_3$  relations from Campbell et al. (1986); Pagel et al. (1992); Izotov et al. (1997); Deharveng et al. (2000); Oey & Shields (2000); Pilyugin et al. (2006b). Our one-dimensional  $t_2 - t_3$  relation is shown by the plus signs. Our two-dimensional  $t_2 - t_3$  relations for different values of the excitation param-

ter are shown by the triangles ( $P = 0.9$ ), the open circles ( $P = 0.5$ ), and the open squares ( $P = 0.1$ ). Examination of Fig. 6 shows that the  $t_2 - t_3$  relations of Pagel et al. (1992) and Izotov et al. (1997) are relatively close to our two-dimensional relation for high excitation H II regions, while at low temperatures, the  $t_2 - t_3$  relations of Campbell et al. (1986) and Deharveng et al. (2000) are relatively close to our two-dimensional relation for moderate excitation H II regions.

#### 4 CONCLUSIONS

A relationship between the ratio of nebular to auroral nitrogen line intensities, which is an indicator of the electron temperature  $t_2$  in the  $O^+$  zone of H II regions, and nebular oxygen line intensities in spectra of high-metallicity H II regions was derived. Since the oxygen nebular lines are strong and, consequently, are easily observable, the derived relation coupled, with the ff relation derived in our previous studies (Pilyugin 2005; Pilyugin et al. 2006a), solve the problem of the determination of the electron temperatures  $t_2$  and  $t_3$  in high-metallicity H II regions where faint auroral lines are not detected. It should be emphasized that the relation obtained here and the ff relation are purely empirical relations in the sense that they are relations between directly measured values. Consequently, there is no assumptions at the base of those relations.

The derived relation and the ff relation confirm our idea that the diagnostic line ratios, which are indicators of the electron temperatures, can be expressed in terms of the strong oxygen nebular lines. This, in turn, confirms the basic assumption of the “empirical” method, proposed by Pagel et al. (1979) a quarter of a century ago, that the oxygen abundance in H II regions can be estimated from strong oxygen line measurements only.

The relation between electron temperatures in the  $O^{++}$  and  $O^+$  zones in high-metallicity H II regions was investigated. It was found that there is no one-to-one correspondence between  $t_2$  and  $t_3$  temperatures. Instead the  $t_2 - t_3$  relation is dependent on the excitation parameter.

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